SOLID-STATE LIGHT-INTENSITY CONTROLLER FOR BIOLOGICAL RESEARCH

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SOLID-STATE LIGHT-INTENSITY CONTROLLER FOR BIOLOGICAL RESEARCH

By K. R. Beerwinkle and I. L. Berry[1]

ABSTRACT

A solid-state light-intensity controller for incandescent lamps was designed and constructed to simulate natural dusk and dawn in enviromental chambers for biological research. An RC timing circuit is used with negative feedback to give switch-selectable transition periods from 15 minutes to 3 hours in length. Average absolute voltage change to the lamps is linear and no expensive motors, gear drives, or autotransformers are required.

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INTRODUCTION

Simulation of twilight corresponding to natural dusk and dawn is frequently necessary in environmental chambers used for entomological and other biological research. Several electromechanical systems have been developed to serve this need. Fowler et al. (*2*)[2] used a motorized mechanical-shutter arrangement, and Daterman (*1*) used several banks of lights which were sequentially controlled. Levin et al. (*4*) and Wood (*8*) used reversible motors to drive autotransformers. Sparks (*6*), Moody et al. (*5*), and Tanabe (*7*) described systems in which small direct-current motors were programed to rotate the controls of solid-state dimmer switches. While such systems may perform satisfactorily, a totally solid-state control is more desirable because the difficulty in constructing a motor and gear-driven arrangement can be avoided, and no expensive autotransformers or motors are required.

The incandescent-lamp controller described here is totally solid-state except for one electromechanical relay. Four inexpensive, active semiconductor devices are used in a phase-control circuit to provide switch-selectable transition periods of up to 3 hours in duration. Negative feedback is used to make the change in average absolute alternating-current voltage across the lamps linear with time.

CIRCUIT DESCRIPTION AND CONSTRUCTION

Phase control using thyristors has become one of the most common means of controlling power to electric motors, lamps, and heaters. With an alternating-current voltage applied to the circuit, a gated thyristor such as a triac remains in its off state for the first portion of each half-cycle of the powerline frequency, and no power is applied to the load. Then, at a time (phase angle) determined by the control circuit, the thyristor switches on for the remainder of the half-cycle, supplying load power. By controlling the phase angle at which the triac is switched on, the relative power in the load is controlled. Unijunction transistors are often used to provide synchronized trigger pulses to switch on thyristors at the desired phase angles. Phase-control theory and applications are discussed in detail by Zinder (*9, 11*) and Haver and Zinder (*3*).

Triac D_1 in figure 1 controls the power to the incandescent lamps. A unijunction transistor circuit consisting of Q_3, T_1, R_6, and C_3 provides a synchronized gate pulse to D_1. The conduction phase angle of D_1 is dependent on the charging rate of C_3 in the trigger circuit.

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[1] Agricutural engineers, Veterinary Toxicology and Entomology Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, College Station, Tex. 77840.

[2] Italic numbers in parentheses refer to items in "Literature Cited" at the end of this publication.

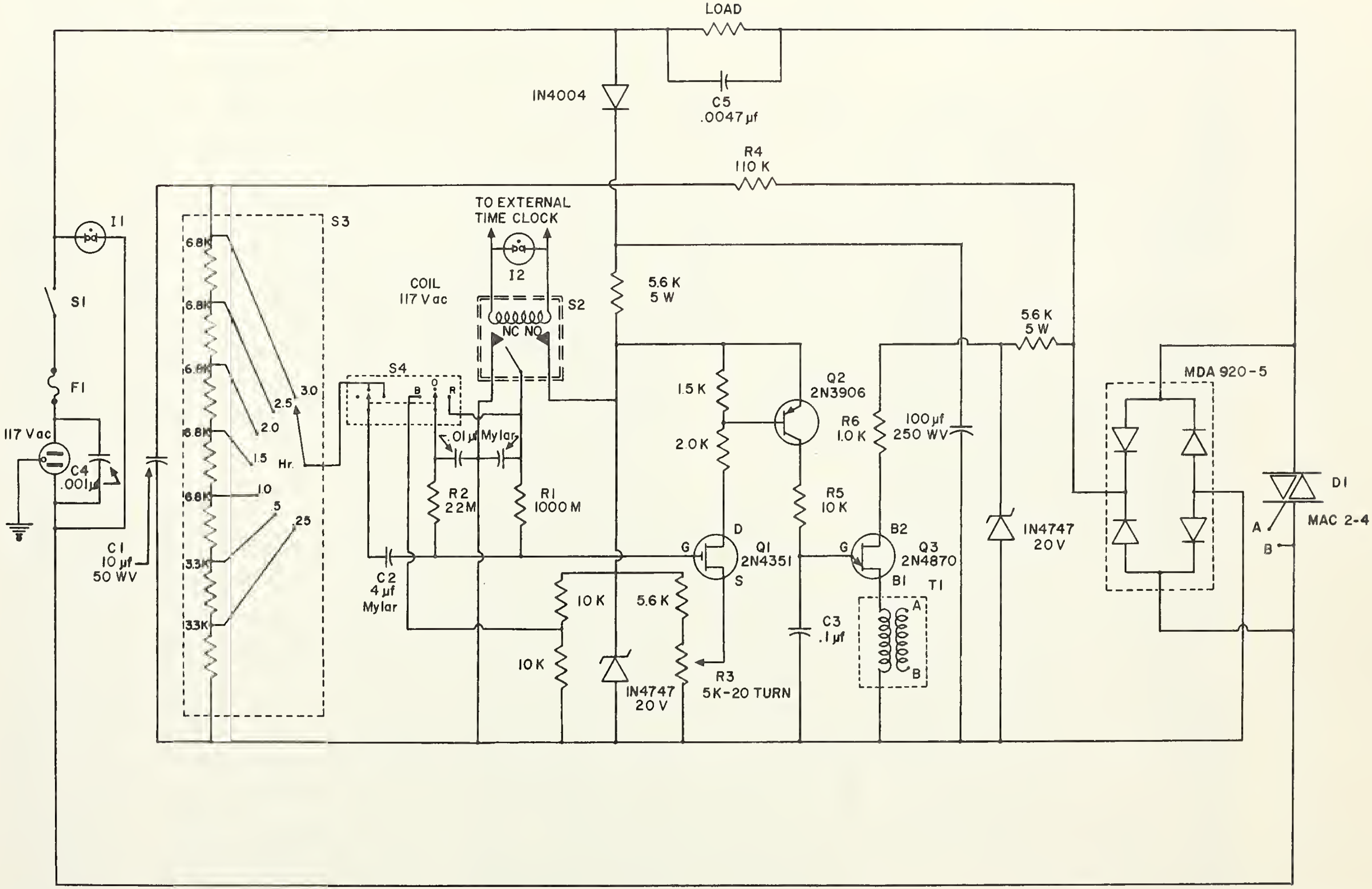


Figure 1.—Schematic of solid-state dimmer control. All resistors are one-half watt unless otherwise indicated. T_1 is a Sprague 11Z12 pulse transformer, and S_2 is a Potter and Brumfield SPDT relay No. KNP–5A21 or equivalent. The 1,000-megohm resistor R_1 is available from Victoreen Instrument Division of VLN, 10101 Woodland Ave., Cleveland, Ohio 44104. I_1 and I_2 are neon indicator lights with series resistors for operation on 117 volts ac.

The two transistors, Q_1 and Q_2, form a high-ain direct-current amplifer, which controls the harging rate of C_3 and thereby the conduction hase angle of D_1. The diode bridge across D_1 rovides synchronization for the unijunction ansistor trigger circuit and negative feedback hrough R_4. The negative feedback current is ltered by C_1, and the voltage across the dividing esistors in S_3 is approximately proportional to he average absolute voltage across D_1 and inersely proportional to the average absolute oltage across the load.

During normal operation, when the power to he load is only partly on, the operation of the rcuit is similar to that of an inverting operaonal amplifier wired in an integrating mode. he gate of Q_1 is a summing point for negative eedback current through C_2 and the current hrough R_1. Whenever the voltage at this summing point deviates from an equilibrium point, he error is sensed by Q_1, amplified, and applied o the load in the form of a change in alternatng-current power. The resulting change in egative feedback corrects the error and returns he gate voltage to the equilibrium point. Since he voltage on the gate of Q_1 remains constant hile power is changing to the load, the voltage cross R_1 is constant, and the feedback voltage cross C_2 must vary linearly to compensate for he constant current through R_1. Therefore, the verage absolute output voltage must also vary nearly to maintain the linear feedback voltage.

The voltage on the gate of Q_1 is about 10 and s set by moving S_4 to the balance (B) position nd adjusting R_3 until the average absolute voltge to the load is one-half of maximum. Then, ith S_4 in the operate (O) position, positive urrent through R_1 when S_2 is switched to 20 olts equals the negative current when S_2 is witched to zero volts, and the rate of average bsolute voltage change to the load is similar, hether increasing or decreasing.

When the power to the load is either fully off r fully on, negative feedback is at a maximum r a minimum, and the constant voltage is no onger maintained on the base of Q_1. Therefore, t the end of each transition period, this voltage harges or discharges exponentially to the voltge determined by the state of S_2 (0 or 20 olts) and remains there until S_2 is changed. When S_2 is switched, the voltage again changes xponentially until it reaches about 10 volts, at which point feedback control is established, and the average absolute voltage to the load begins to change linearly. The delay between switching of S_2 and beginning of power change to the load is determined by the RC time constant of R_1 and C_2 and the residual charge on C_2 at the time of switching. This delay is a maximum of 46 minutes when C_2 is fully charged or fully discharged and must be considered as lag time when setting the external time clock that controls S_2.

The time required for the linear transition period is given by $T=(\Delta V \times C)/I$, where T=time in seconds for transition period, ΔV= total feedback voltage change during transition at selected S_3 position, C=capacitance of C_2 in microfarads, and I=current through R_1 ($\sim 10^{-8}$ ampere).

Transition periods from 15 minutes to 3 hours in length are selected by S_3 to obtain the proper value of ΔV to satisfy the above equation for the desired time. The value specified for R_4 is the theoretical value derived with the assumption that all components are perfect. To compensate for component tolerances in each individual circuit, the value of R_4 may need to be increased or decreased slightly to give the transition periods indicated.

Setting S_4 to the reset (R) position places R_2 in parallel with R_1 and reduces the transition time by a factor of approximately 50 for each set point of S_3. The switch is used to reduce the time required for transitions during checkout procedures and to rapidly reset the operating point of the control circuit as necessary because of power interruption or changed control schedules.

The maximum full-on voltage applied to the lamps is controlled by the maximum conduction phase angle allowed by the trigger circuit. In this design, this angle is approximately 150 degrees and is determined by R_5 when Q_2 is in saturation. The 150-degree phase angle with 120 volts root mean square of input corresponds to approximately 114 volts root mean square and 100 volts average to the load.

The incandescent lamp load is limited to 800 watts by the maximum current rating of D_1. For loads greater than 100 watts, D_1 should be mounted on an aluminum plate or other adequate heat sink. Fuse F_1 protects the circuit and is sized to correspond to load current. Neon indicator I_1 is a pilot light for main power, and

I_2 indicates when S_2 is in the position for increasing power to the load.

The complete control circuit was assembled using a printed circuit and was housed in a single chassis with external leads provided for 117 volts (ac) of input power, output power to the load, and connection of relay switch S_2 to the external time clock. The chassis was grounded through the alternating-current power plug. Total component cost, excluding time clock, was about $50.

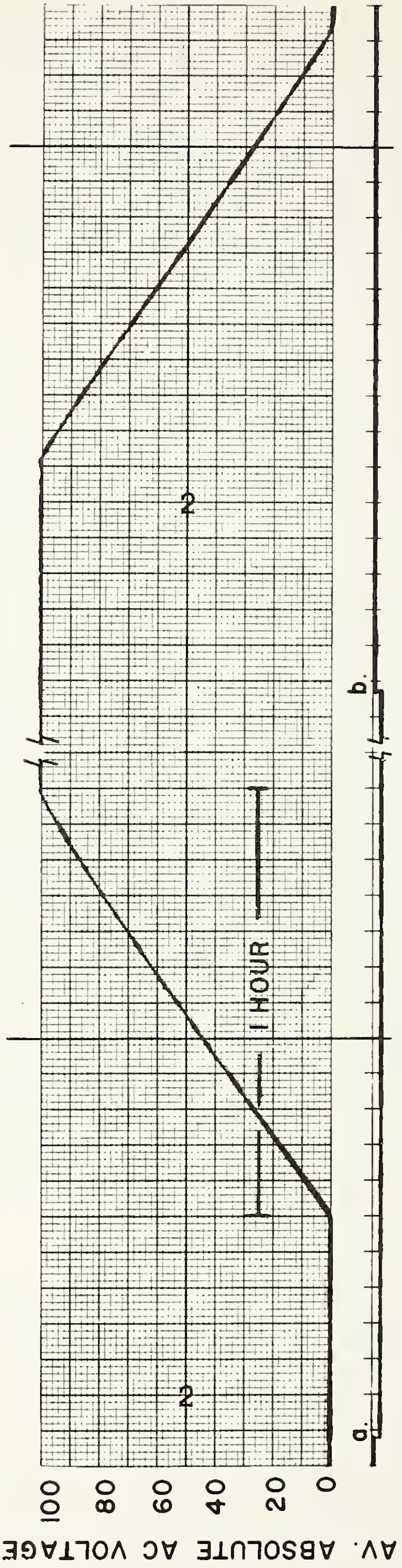
RESULTS AND DISCUSSION

A typical recording of average absolute alternating-current voltage change to the load during 1-hour transition periods is shown in figure 2. For optimum transition linearity over the specfied time periods, the combined gain of Q_1 and Q_2 and the conversion efficiency of Q_3 and D_1 must be high so that a minimal change in voltage at the gate of Q_1 will produce a large change in output power. Also, the maintenance of high input impedance at the gate of Q_1 is imperative. Thus, Q_1 must be an insulated-gate field-effect transistor, C_2 must be a low-leakage capacitor, and circuit assembly techniques must be such that high impedance is preserved.

During periods of active power change to the load, the switching of the triac will generate some radio-frequency (RF) noise which may interfere with AM radio reception or with precision instrumentation and controls in the immediate area. Filter capacitors C_4 and C_5 suppress the RF noise slightly. Zinder (*10*) discusses methods for more complete suppression of RF noise in thyristor circuits.

The feedback network of this circuit detects the average absolute voltage across the triac. Hence, this parameter increases or decreases at a linear rate in time. A more elaborate circuit might be devised to detect and control the root mean square voltage. However, since neither of these parameters is linearly proportional to power nor to light output of incandescent lamps, average absolute voltage was used because it is easier to detect.

It should be noted that all parts of the control circuit are at an alternating-current potential different from chassis ground. Thus, caution is necessary to prevent electrical shock while assembling and checking out the circuit.



Three complete solid-state light-intensity con-
llers have been built and used successfully by
ooperator in entomological research to stimu-
e crepuscular activity of mosquitoes.

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AGRICULTURAL RESEARCH SERVICE
SOUTHERN REGION
P. O. BOX 53326
NEW ORLEANS, LOUISIANA 70153

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